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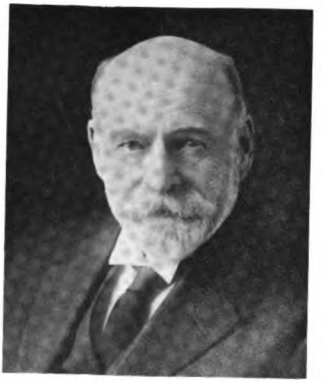

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TUNGSTEN IN COLORADO

DEPARTMENT OF EDUCATION
SEP 8 1910
LELAND STANFORD JUNIOR UNIVERSITY.

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Issued Quarterly by the Colorado School of Mines
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Tungsten in Colorado.*

H. R. Van Wagenen.

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PART I.

Occurrence.

In Colorado tungsten occurs in commercial quantities in Boulder County. It has been found in other parts of Colorado, notably Gilpin, San Juan, Lake, Ouray, Teller and Dolores Counties. Very recently tungsten has been discovered near Cripple Creek, Colorado (see "Tungsten at Cripple Creek," Min. Rep., Feb. 2, 1905, p. 133). Even more recently a very promising discovery of hubnerite has been made in Gilpin County just over the line from Clear Creek County.

Elsewhere tungsten is found in Arizona (see "Notes on Tungsten Deposits in Arizona," Forbes Rickard, E. & M. J., V. 78, p. 263); in South

* The Frenzel prize thesis.

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Dakota (see "Tungsten Ores in Black Hills," Min. Rep., V. 50, p. 217); in Connecticut (see "A Remarkable Deposit of Wolfram Ore in the United States," Trans. Am. I. of M. E., V. 22, p. 236); in Nevada (see "The Osceola, Nevada, Tungsten Deposits," F. D. Smith, E. & M. J., Mch. 1, '02, p. 304); in Washington (see "Tungsten Deposits in Washington," W. S. Thyng, E. & M. J., Mch. 22, '02, p. 418); and in New Mexico, Oregon, Idaho, Montana and North Carolina; also in Australia (see "Tungsten in Australia," E. & M. J., V. 78, p. 900); in Cornwall, England; Saxony, Germany, Spain, Portugal, Sweden (see "Tungsten in Sweden," Min. Wld., Dec. 3, '04); in Austro-Hungary, Bohemia, Canada (see "Tungsten Ores in Cape Breton," A. C. Ross, E. & M. J., Sept. 23, 1899, p. 370); in Brazil, Peru (see "Tungsten in Peru," T. A. V. de Habich, Bulletin 11 of the Peruvian Corps of Mining Engineers), and in Japan (see "Tungsten Deposits of the Kurasawa Mine, Province Kai, Bulletin Geol. Survey of Japan, V. 17, p. 23).

Tungsten occurs as wolframite in most parts of Colorado, but as hubnerite principally in San Juan County.

Occurrence in San Juan County, Colorado.

In San Juan County tungsten occurs in the mineral hubnerite in solid streaks and bunches which are clearly differentiated from the quartz gangue. Though the streaks are often thin, the hubnerite is not scattered through and intermixed with the quartz as is the Boulder County wolframite.

Fluorite in small quantities is a common associate, and pyrite, chalcopyrite and galena usually occur in the vein or with the country rock which generally is an andesite.

The ore occurs at the Adams claim on Bonita peak; the Dawn-of-Day, Sunshine and Minnesota claims in Dry gulch; the Natalie and Big Colorado mines near Gladstone; the North Star, Empire-Victoria, and Little Dora mines on Sultan mountain, and at the Tom Moore mine in Burns gulch.

The Adams claim is at an elevation of about 11,300 feet on the southwestern slope of Bonita peak and about 700 yards up the gulch leading directly north from the railroad station in Gladstone.** The hubnerite occurs associated with pale green fluorite in a quartz vein which strikes N. 10° E., dips E. 75° and is three or four feet wide. The country rock is a dense silicified and mineralized andesite. Pyrite, though in very small crystals, is present in considerable quantity. Remnants of plagioclase feldspar are evident under a glass. The hubernite is not of a constant width, but divides itself into wandering veinlets or stringers, or gathers in masses of pure mineral perhaps two inches in width and six inches to eight inches in length, but in all cases is clearly differentiated from the gangue and is not scattered or mixed through the quartz. The hubernite has a bronze-brown color, bright on fresh fracture. It is in bladed prisms often radial and coated occasionally with the yellow tungstic oxide. The

**Gladstone is in Cement Creek about nine miles from Silverton, and can be reached by railroad.

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mineral adheres very strongly to the quartz. The workings consist of two adit tunnels the lower of which is 40 feet long, the upper (40 feet vertical height above the lower) is 30 feet long. A shaft from the upper tunnel cuts in beyond the breast of the lower one and is partially filled with water. Above the upper tunnel are four open cuts along the out-crop, each revealing the hubernite. No record of ore shipped could be found, but hubernite from this claim has been concentrated at the Red and Bonita mill which is 400 or 500 yards below the Adams claim. Considerable hubernite was found on the dump. The origin of the ore is not apparent. That the deposit is not due to descending waters is evident from the fact that the vein is not streaked or stained as would be the case had descending waters passed through this mineral, so rich in manganese.

Dry gulch is tributary to Cement Creek, three-fourths of a mile below Gladstone, and extends upward in a northwesterly direction. The Dry Gulch property is the most important tungsten claim in the gulch, having shipped some three or four tons of concentrates in 1900. This claim is on the south side of the gulch at an elevation of 11,700 feet. The vein, which consists of quartz, strikes N. 20° W., dips 54° E. and is from one foot to four feet wide. The walls are similar to those of the Adams claim. A small amount of pale-green fluorite associated with the hubnerite was found here also. The hubnerite is very similar in color to that found at the Adams claim. The vein had been tunneled for about 120 feet and stoped in parts for a few feet. This is the property from which was mined considerable of the tungsten which was shipped to Germany in 1900. At the breast and on the floor of the tunnel as well as all along the roof the vein continued strong and persistent.

On the Sunnyside and Minnesota claims there are only openings. The out-crop of the same vein, which traverses the Dry Gulch claim, passes through these claims. It was noticed that at both openings the hubnerite appeared in a lead about one to four inches wide and bunched somewhat as at the Adams claim.

The Dawn-of-Day claim is within a few hundred feet of the Dry Gulch claim. The vein dips 68° E. and strikes N. 40° W., which is more to the west than that of the Dry Gulch vein. The vein, gangue, and country-rock are similar to those of the Dry Gulch claim. The workings are 50 feet in length.

The Natalie mine is about one and one-half miles up an unnamed gulch which branches to the southeast from Cement Creek directly out of Gladstone. The mine is quite extensive, and has been worked for gold, silver, and lead. When visited by the writer (December, 1904,) it was flooded with water and inaccessible. It was learned from the foreman that the vein, 18 feet wide, is of quartz with copper, iron, and argentiferous galena. The gold is free. The tungsten occurs as hubnerite in large bunches of short, flat crystals, or as short, black, bright needles in extremely small fissures in the quartz. One three-foot vein was found which ran high enough in tungsten to make mining it profitable, but nearly all the hubnerite had been thrown over the dump because the great majority of it occurred in quantities too small to save. Specimens

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of the small, black needles in the fissures were found on the dump, also a piece of the country-rock, which is the same as the country-rock of the Adams claim, but it carries less pyrite.

The Big Colorado mine is directly across the gulch from the Natalie. It was closed and inaccessible. All that could be learned was that the tungsten was even rarer than in the Natalie but of similar occurrence.

The North Star mine is situated on the northern slope of Sultan mountain, about one mile southwest of Silverton. It has been extensively developed* for gold, silver, and lead. The vein contains much quartz. It is eight feet wide, in places, with pay-streak one foot wide consisting of galena and tetrahedrite, occurring persistently along the foot-wall. Gold is found to a small extent with pyrite in the more quartzose portion of the vein and it is here that the hubnerite is found as a black, needle-shaped mass, or, more often, as scattered needles in the fractures of the quartz.

The Empire tunnel on the northeast slope of Sultan mountain enters at a point about 150 feet above the bed of Mineral creek and has a straight course of S. 35° W. It cuts the Little Dora vein about 1,230 feet from the mouth of the tunnel. This vein strikes N. 20° W., dips nearly vertically and is a clear-cut fissure about two feet wide. The ore is galena, sphalerite, tetrahedrite, chalcopyrite and pyrite in a gangue consisting mostly of quartz and some barite. The country-rock is monzonite. Hubnerite associated with fluorite occurs in bunches of long, black crystals.

The Boston tunnel is 208 feet vertically above the Empire tunnel and about 400 feet to the west. Through it the Empire-Victoria vein is reached. This vein, fairly regular, shows a width up to seven feet. Its dip is somewhat variable, in places as low as 65°, striking parallel to the Little Dora vein. This vein contains the same minerals that are found in the Little Dora and, likewise, is a fissure vein in monzonite. Hubnerite associated with fluorite occurs in streaks and bunches next to the hanging-wall and is usually associated with and surrounded by a soft gangue. The hubnerite is probably of later origin than the rest of the vein. The tunnel is very favorably located for the cheap handling of ores. Both of these lodes have been worked, intermittently since 1876, for gold, silver, and copper.

The Tom Moore mine is in Burns gulch, which is tributary to the Animas river at a point some nine miles above Silverton. The lode is on the south side of the gulch at an elevation of 11,200 feet, strikes N. 53° E. and dips N. W. 68°. There are three tunnels, but the hubnerite is found in the top one only. Here it occurs as small crystals in quartz stringers in a lode three to six feet wide. The lode consists mostly of tetrahedrite with some chalcopyrite and galena; the ore-streak is "frozen" to the walls, a rhyolite flow breccia. The quartz is often accompanied by kaolin, pale-lilac fluorite, and free copper. The hubnerite is in quantities entirely too small to warrant saving it. The mine has been worked for gold, silver, and lead.

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* See Bulletin No. 182, U. S. G. S., p. 251.

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What was said, under the discussion of the Adams claim, about the origin of the hubnerite there holds good throughout the whole San Juan district.

Occurrence in Boulder County, Colorado.

Tungsten occurs in Boulder County as wolframite* and, very rarely, as hubnerite and scheelite. Quartz is invariably the gangue; the vein-walls are granite-gneiss, mica-gneiss, or porphyry.

Unlike the masses of practically pure hubnerite which are usual in the San Juan region, the Boulder County wolframite is generally scattered in very small quantities through the quartz, forming a mass which to concentrate must be crushed very fine. This fine crushing gives rise to the difficulties in milling the ore. Some of the properties owe their high recovery of value, however, to crystalline ore. The ore-streak is not constant, but pinches out occasionally.

Wolframite has been found at Salina, Wallstreet, Gorden Gulch, Caribou, Nederland and Eldora. There are discoveries in many other places between these points, but the mining is at present confined to Gordon Gulch, Caribou, and Nederland.

Gorden Gulch is one mile down Farewell Gulch from the track of the Colorado and Northwestern railroad, which railroad operates between Boulder and Eldora, passing through Salina, Wallstreet, Caribou and Nederland. A quarter of a mile from the intersection of Farewell and Gorden gulches are the mines and mill of the Great Western Exploration Company on the Miser group of claims. This location is a little north of the center of Sec. 34, T. 1 N., R. 72 W. The elevation is 7,600 feet.

Tungsten occurs in quartz veins as streaks of black wolframite, as crystalline aggregates, or finely disseminated through the quartz. The walls of the veins are in some cases granite-gneiss, but more often granite-porphyry or a dyke rock which may be vein-granite. Inclusions of the wall-rock often occur in the quartz.

The veins which have been prospected are the Quaker City, Exchange, Ophir, Major, Little Major, Pride, and Iowa. A number of other veins have been uncovered.

The Quaker City claim is in Upham** Gulch. The vein strikes N. 50° E. and dips N.W. 75°. The outcrop has been uncovered and the vein is visible for 400 feet; at places open-cutting has been done to a depth of 30 feet; the vein varies from 2 to 14 feet in width. The foot-wall is granite-gneiss; the hanging-wall is a hard granite-porphyry (dyke "E"). Running parallel to the Quaker City vein, and some 50 feet horizontal distance to the northwest (90 to 100 feet up the hill), is the Quakerville

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* The name "wolframite" is used in deference to usage in the district rather than to accuracy. In composition the Boulder county tungsten ores do not meet the iron-manganese ratio for wolframite. The correct term for the Boulder County mineral is "ferberite," a ferrous tungstate. See Addendum.

** This is the name given by the U. S. G. S.; the local name is Oldham Gulch.

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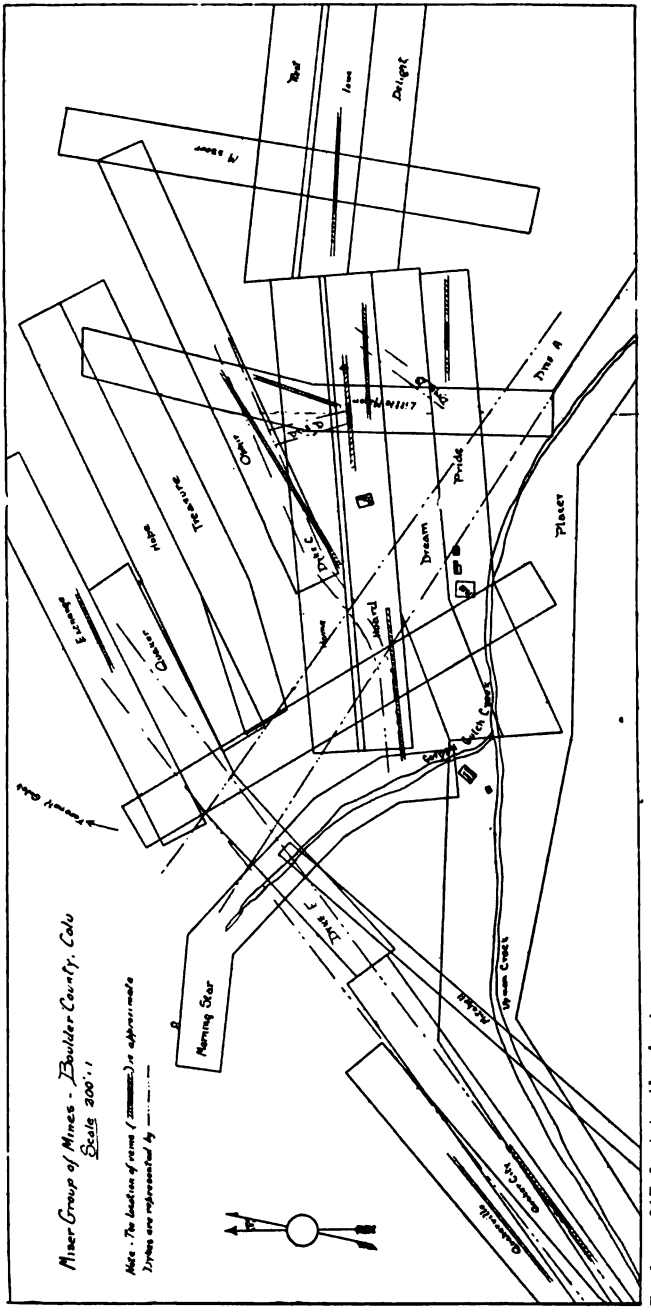

Scale: 617 feet to the inch.

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vein. Along the outcrop are openings from which a little ore has been taken. The vein is from one to three feet wide. A cross-cut tunnel is driven from the road (about 40 feet vertical height below the Quaker City outcrop), cutting in at right angles to the strike of the vein. It cuts the Quaker City vein about 40 feet in. Drifts are being driven along the vein in both directions. Considerable stoping has been done and a winze has been sunk 20 feet farther down in which the ore continues to show. The cross-cut is continued through the dyke 75 feet in where a wolframite stringer was cut. The cross-cut is in 125 feet and has not yet struck any other ore. At the breast the rock is still a hard granite-porphyry, but the crystals are larger than at any other point in the tunnel. The wolframite in this vein is more compact than in the others. It is more intimately mixed with quartz and somewhat resembles black chert or flint.

The Exchange vein strikes N. 20° E., dips 80° Northwest, is 4 feet wide and has been open cut for 80 feet to a depth of 30 feet. The hanging wall of this vein is apparently a continuation of the dyke "E" which forms the hanging-wall of the Quaker City vein. A fairly continuous line of outcrop can be traced between the two lodes, and the rock is practically the same in composition though less porphyritic at the Exchange vein.

The Ophir vein strikes N. 40° E., dips 66° Northwest and is 14 feet wide. There is a shaft 80 feet deep from the bottom of which are drifts in both directions. These extend for 40 feet and the whole body of ore has been stoped out to the surface. It is a strong vein of streaks, stringers and masses—best at the walls. About 60 feet to the North of the shaft the vein is crossed by dyke "C" which appears to cut the ore off short; no wolframite has been found along the outcrop beyond the dyke. A cross-cut tunnel is being driven from the mill to intersect this vein at a depth of 150 feet.

The Major vein strikes N. 45° E. and dips Northwest 75°. It has been cut at a depth of 25 feet by a cross-cut tunnel; drifts extend along the vein for 30 feet in both directions; the vein has been stoped to the surface. Here again are the usual streaks and stringers, and in some places solid ore which, however, pinches out to appear again perhaps on further development.

The Little Major vein strikes N. 25° E. and dips N. 85°. A tunnel was driven on this vein in past years when it was thought to be a silver vein. At present the vein is reached at a point 25 feet below the tunnel by the cross-cut tunnel which opened up the Major vein, for the two veins intersect at this point. The wolframite is in three distinct streaks with intermediate stringers, and therefore the vein has been opened for a width of 8 to 10 feet to get all three stringers.

The Pride vein is reached through the same cross-cut tunnel that opened up the Major and Little Major veins, for the Hoard—another silver vein—intersects the Major veins at this point, and by following through a tunnel in this Hoard vein for 150 feet and then cross-cutting for 40 feet the Pride vein was struck at a depth of 80 feet. This vein has been opened for a width of 22 feet without reaching the foot-wall. The wol-

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framite is in the usual occurrence in the walls. This vein has been worked at the surface along the outcrop for 150 feet.

The Iowa vein strikes N. 70° E. and dips N. 80°. A drift extends along the outcrop for 100 feet, showing two two-inch seams which combine and then pinch out. Scheelite in crystals (pyramidal hemihedral tetragonal, showing pyramids of the first, second and third order) is occasionally found here with the wolframite.

There is an unnamed lode one-quarter of a mile down Gorden Gulch from the mill in which the wall rocks are a little different from the walls of the other wolframite veins in this district. Instead of being porphyry they are granite-gneiss in which occasionally are very small flakey grains resembling metallic silver.

The veins have thus far been discussed simply as ore-bearing veins; their relation to geological structure will now be shown in the discussion of the dykes of the area. With regard to all of these dykes (with the exception of dyke "E") the question is open as to whether they are dykes or veins. Those most in question are dykes "C" and "D".

Crossing the Miser Group are a number of dykes which are as a usual thing cut through by the veins, but in a few cases the lode ends at the intersection with a dyke. The country-rock strikes N. 65° E.

Dyke "A" is from 50 to 100 feet wide. The rock in some respects resembles a vein-granite, in others a porphyry; the presence of orthoclase and quartz and the absence of porphyritic structure suggest a mica-less vein-granite. The occurrence as a dyke in the same region where another well marked dyke of granite-porphyry occurs—namely, dyke "E"—suggests that this rock itself may be a granite porphyry less porphyritic than that of dyke "E". The veins cut into the dyke without apparent effect to either.

Dyke "B" is very short, appearing to terminate after crossing the Hoard vein at which crossing the wolframite was very rich, but beyond (to the east) no more wolframite has been found.

Dyke "C" intersects the Ophir vein which carries a very good grade of ore; beyond this intersection (to the N.E.) no wolframite has been found. This dyke makes a decided bend as it comes to the Hoard vein which it parallels and forms the hanging-wall. Wolframite was found at but two places along this contact, and these are mere pockets less than 50 feet in depth. The rock of this dyke is similar to that of dyke "A".

Dyke "D" forms the ridge of a hill. It appears to end at its intersection with dyke "C." At its other end it seems to stop abruptly at the Major vein, of which it forms the hanging-wall, not by paralleling it, but by coming in contact at right angles to the vein and ending short. It will be remembered that the ore in this Major vein pinched out in both directions along the vein in about 60 feet total length; this is not far from the width of this terminating dyke. The best ore was found against this hanging-wall (the dyke) and was high grade—an almost solid mass 18 to 24 inches wide.

The main dyke of the region has already been noted as the hanging-wall of both the Quaker City and Exchange veins. It is a granite-por-

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phyry, in places noticeably porphyritic, but as frequently lacking the porphyritic structure. The dyke is 75 feet wide, approximately parallel to the foliation of the region, continues five or six miles to the S.E. and N.W. at least to the Exchange vein. At the Quaker City lode it is walled on both sides by granite-gneiss. At its N.W. contact with the granite-gneiss it becomes strikingly granitic with unusually large phenocrysts of feldspar. The breast of the cross-cut tunnel in the Quaker City lode is in part of the dyke.

Generally, then, the ore deposits are very irregular in width and per centage of wolframite. Many veins pinch out quickly. As depth is attained the veins seem to be somewhat wider. About 600 tons of concentrates averaging 60% WO_3 have been taken out from all of these veins. The concentration was 1 into 10 or 15.

The ore is treated at the company's mill located at the mines. During 1904, 400 tons of concentrates averaging 60% WO_3 were produced in Boulder County. This is about 80% of the total production of the United States. Half of this was mined by the Exploration Co.

Caribou and Nederland will be discussed under the same head because the mines are scattered between the two.

The Boulder County Co. treats its ores at its mill at Caribou. The Boulder County mine is a mile and a half N.E. of the Caribou station. There are two parallel veins striking N. and S. and dipping 85° E. A shaft has been sunk 145 feet deep. At the bottom are drifts in both directions for 30 feet and 40 feet. The vein is eight feet wide, strong at both walls, with stringers and streaks throughout. At a depth of 45 feet there is a level which is in good ore to the South, but pinches out to the North. A cross-cut to the West 25 feet in length opens the parallel vein (above mentioned) and drifts are being driven in both directions. The ore continues persistently to the South where the claim end-line is reached. To the North the vein pinches out. The foot-wall is a granite-gneiss. The hanging-wall has a capping 12 to 18 inches wide of vein-granite somewhat resembling porphyry behind which the country-rock is the same as the foot-wall.

The Colorado Tungsten Corporation's mine is 200 yards to the west of the Boulder Company's mine. The vein strikes N. 20° E. and dips E. There are two shafts 390 and 210 feet deep respectively. The first has levels opened up from a depth of 315 feet to the surface and the second has a level at 180 feet to the surface. There are twenty-five openings in all which have produced ore. The mine is drained by the Boulder County Milling Co. tunnel at a depth of 300 feet. The walls are both porphyry, carrying a small amount of hematite and galenite. The wolframite shows some crystals and is of a very good grade. Small crystals of galenite were found with the wolframite crystals. The ore is treated at the Boyd mill in Boulder.†

The Wolfe-Tongue Company's shaft No. 1 (The Oregon mine) is on the same vein as is the Boulder Company mine and is 100 yards to the south of the latter's shaft. The shaft is down 111 feet and there are

† See Addendum.

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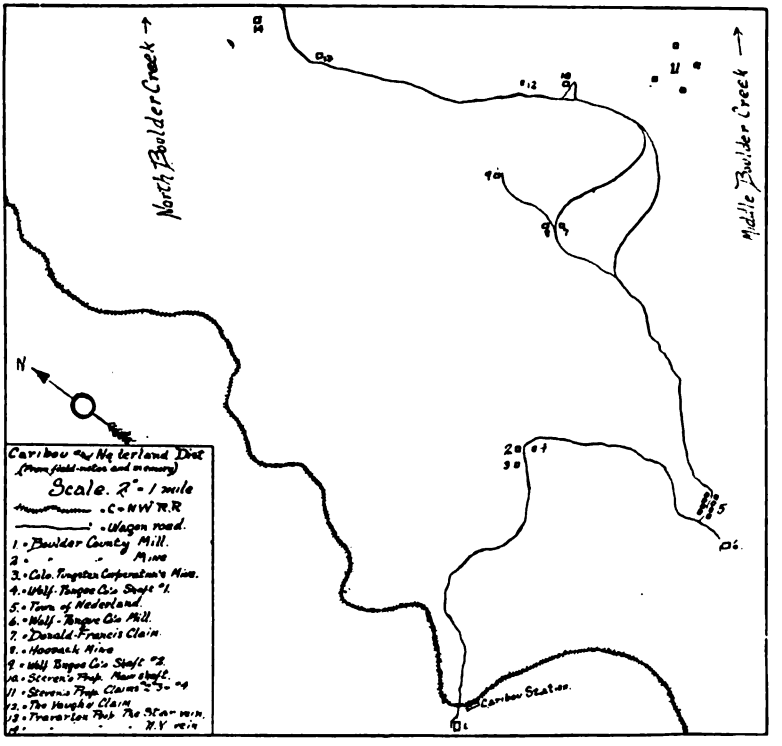
drifts in both directions along the vein at 40 and 60 feet. At the 40 foot level there is a drift for 30 feet to the south which continues in good ore. To the north is a 90 foot drift, which ends at the Boulder County Company's claim end-line. Shaft No. 2 (the Clyde mine) is on a vein which strikes N. 50° E. and dips 75° N.W. This shaft is 125 feet deep with levels at 50 feet and 100 feet.* The 50 foot level is drifted 150 feet to the east and has been stoped out to the surface; no development has been done to the west. At the 100 foot level a drift extends 125 feet to the



Scale: 4 miles to the inch.

east and stoping has been done to a height of 30 feet. There is much good ore in this mine, the best of which occurs in "mud" which is a decomposed mica-gneiss. The foot-wall is mica-schist and fine-grained vein-granite; the hanging-wall is porphyry. This Company has many smaller prospects in this general vicinity; one of the most promising is the Donald-Francis vein on Hurricane Hill. The Hoosier vein is about 150 feet north of the Donald-Francis vein. Here there is a 40-foot shaft on a three-foot vein which strikes N. 70° E. No drifts have been driven. The

* See Addendum.

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gangue is quartz and the walls are granite-gneiss. The ores from the properties of this Company are treated at the Company's mill at Nederland.

The Stevens Group. On claim No. 1 (see map) is a 50 foot shaft with drifts 150 feet to the north and 20 feet to the south—all in good ore. The vein strikes N. 25° E., is four feet wide, and consists of very compact masses of wolframite impregnating quartz within wall rocks of granite-gneiss. In the vicinity of Claims Nos. 2, 3 and 4 there are many prospect holes which indicate the presence of a number of wolframite veins. On Claim No. 2 is a 30 inch vein striking N. 10° E. which has been tunneled for 35 feet. The wolframite is with quartz in a country-rock of granite-gneiss. Claim No. 3 has a 30 foot tunnel on an 18-inch vein which strikes N. 2° W. The ore is good in places, but pinches out. The gangue is quartz and the walls are granite-gneiss. Claim No. 4 has been developed but very little. There is a vein here remarkable in that it presents but a single outcrop which might readily be mistaken for a boulder. The excavations on both sides of it, however, prove it to be in place, and further show extension in both directions. The vein is quartz and the wolframite is scattered through it in stringers and large masses, very finely grained and compact. The excavation reveals 14 feet of very characteristic wolframite ore, i. e., rich in spots and barren in others. The gangue is quartz and the country rock is gneiss—more micaceous than usual and therefore more correctly termed a mica-gneiss. The ores of the Stevens' property are shipped via the Denver, Northwestern & Pacific Railroad from Rawlins (four miles away) to the Company's mill in Denver—the Henry E. Wood Ore Testing Works.

There are a number of tungsten veins on the Travarton farm which is on the ridge between North and Middle Boulder Creeks. On the Star vein is an 85 foot shaft, at the bottom of which are drifts 150 feet long in both directions. The vein strikes E. and W., dips N. and is two to three feet wide; the gangue is quartz and the walls porphyry. Good ore has been taken out of this vein and indications are strong for continuation at depth.

The New York vein strikes N. and S. and dips W. At the bottom of the 40 foot shaft the vein has been opened a width of 12 feet without reaching the hanging-wall. The gangue is quartz and the country-rock the usual granite-gneiss.

On the Pansy claim is a 25 foot shaft from which a very high grade ore has been taken, running perhaps 40% wolframite for a width of 8 to 10 inches. There are a number of other prospects on this property not as much developed as the ones mentioned.

Generally, then, it will be noticed that the majority of the veins in the region strike at an average of N. 25° E., that the gangue is the same throughout, and that the wall-rock with but few exceptions is a granite-gneiss. These exceptions apparently have no marked effect upon the richness of the ores. It will be observed that there is a similarity between the Nederland and the Gorden Gulch districts in that the vein occurs in granite-gneiss which may locally become micaceous. In the Nederland district, however, there does not seem to be the same connec-

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tion that holds in the Gorden Gulch district between the veins and dykes of porphyry or granite.

The Salina-Wall Street district is mining only a small amount of tungsten ore. In the Grand View gold mine near Salina wolframite is found in masses and streaks at a depth of 230 feet, but in quantity too small to save. The Eldorado tunnel, Gold Hill mining district, has tungsten in sight, but in very small quantity; no mining is being done. The Black Swan mill, a quarter of a mile below Salina, treated wolframite from the Oregon and XYZ mines (prospects) in Gorden Gulch, and from some prospect holes in Bummers Gulch, two and a half miles south of the mill, on North Boulder Creek. At Wall Street the wolframite is in pockets and short chutes in a quartz vein.

Mill Practice.

The milling of Colorado tungsten ores is divided into two classes: First, the method of milling adapted to the San Juan County ores; and, second, that adapted to Boulder County ores. This distinction is due to the fact that Boulder County tungsten ore, wolframite, is scattered through and intimately mixed in extremely fine particles with the quartz gangue; while the San Juan County tungsten ore (hubnerite) is in masses and streaks clearly differentiated from the quartz. The treatment of the San Juan ore is therefore quite simple. Because of its specific gravity (7.2 to 7.5) there is little or no trouble in obtaining a concentrate nearly free from quartz, but the pyrite, chalcopyrite and galenite—whose specific gravity approach that of hubnerite—are very sure to find their way into the concentrate and must be separated by a method not dependent upon difference of specific gravity.

Formerly the purchasers of tungsten ores demanded a concentrate containing not less than 60% WO_3 (tungstic acid), which means from 78.6 to 85% (Fe, Mn) WO_4, depending upon the % of Mn present. This gives a 15 to 20% quartz margin; that is to say, the amount of silica determines the per cent. of WO_3, for the Fe and Mn bear a constant relation to WO_3. To obtain this the mills, of necessity, rejected quartz carrying values in wolframite. To save this wolframite has been the problem in Boulder County practice. At present the purchasers will take 40% WO_3, which means from 52.5 to 60% wolframite, leaving a margin for 40% silica, so the quartz carrying the slime values of wolframite is run into the concentrate and thus a larger saving is made. But the price is not as high for a concentrate running 40% WO_3 as for a 60% concentrate.

The mills treating, or that have treated, tungsten ores are: The Great Western Exploration Mill,* the Boulder County Mill,* the Wolf-Tongue Mill,* the Boyd Mill,* The Henry E. Wood Ore Treating Works,* the Black Swan Mill*, and the Red and Bonita Mill.**

The Great Western Exploration Company's Mill.—Ore is shoveled from wagons at the back and high up on the hill over a two-inch grizzley;

*For location of this mill see "Geology of Boulder County."

**For location of this mill see "Geology of San Juan County."

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the oversize goes to a 7 by 10 Blake crusher; all the ore goes to a 10-stamp battery, the stamps of which weigh 1,000 pounds, drop eight inches, eighty times per minute, through a 20-mesh screen*, by launder to classifiers which make two products, the larger to Wilfley concentrating table No. 1, the slimes to another classifier, the coarse product of which feeds Wilfley No. 2, and the slimes go to still another classifier, the coarse product of which goes to Wilfley No. 3, and the fine product (a slime) to Wilfley No. 4.

Wilfley No. 1 makes four products; the first is a finished concentrate, the second is a middling which goes to the distributing tank, the third is a waste of coarse sand, and the fourth is a slime which also goes to the distributing tank. It will be noticed that it is a streak of intermediate position that is disposed of. Wilfley No. 2 makes four products; first is a concentrate, second a middling—to the distributing tank, the third is pumped back to the battery—a sand too coarse for the slimers which follow—and the fourth to the distributing tank. Wilfleys Nos. 3 and 4 each make four products; the first is a concentrate, the second a middling sent to the distributing tank, the third is waste, and the fourth to the distributing tank.

The distributing tank makes no separation or classification, but feeds three slimers which are home-made products quite similar to vanners. The distributing tank is to be replaced by a "Callow's Settling and Pulp Thickening Tank," a description of which may be found in Bulletin No. 100, Utah Mining Machinery and Supply Company, Salt Lake City. The slimers each make three products, a concentrate, a middling (which is elevated and fed back into the battery), and a tailing which goes to a settling tank, the overflow of which runs to the creek.

The capacity of the mill is 12 tons per 12-hour run. The concentrates are dried in the usual manner and shipped in canvas sacks. The average concentration is 15 into 1.

The Boulder County Mill.—Ore is hauled by team from the mine to the top of the mill, where it is thrown on 2-inch grizzleys, from which the over-size goes to a 7 by 10 Blake crusher and then to a 10-stamp battery, of which the stamps weigh 750 pounds, drop 8 inches, 64 drops per minute. Passing out through a 12-mesh wire screen the ore goes direct to two Wilfley tables (No. 4), each of which makes two products—a finished concentrate and a tailing. The tailings are elevated to a tank, thence to two classifiers. The sand from the first classifier goes to Frue vanner No. 1 and the slimes to classifier No. 2, from which the coarse goes to Frue vanner No. 2 and the slimes to vanner No. 3. No. 1 vanner is 4 feet by 12 feet and has a corrugated belt. Numbers 2 and 3 are 6 feet by 12 feet with smooth belts. On the slime end of vanner No. 3, the one which received the finest material from the classifiers, was a red-brown color, due to the slimes passing off. The streak of wolframite may be reddish-

* It is found that this ore which passes a 20-mesh screen is composed of about 50% which will pass an 80-mesh screen, and so on down to 200-mesh; then there is some which remains in suspension—a slime.

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brown. The mill is very well arranged, and the machinery is in good condition. The concentration is 15 into 1. Capacity, 25 tons in 24 hours.

The Wolf-Tongue Company's Mill.—The ore is dumped into bins from the wagons, thence over 2-inch grizzleys, through a 7 by 10 Blake crusher to a twenty-stamp battery, the stamps of which weigh 1,000 pounds, drop six inches, ninety times a minute, through a 20-mesh long-slot screen; thence by launder to a hydraulic classifier which makes three products. The coarse goes to two No. 5 Wilfley tables, the middlings to a No. 3 Wilfley, and the slimes to two other No. 3 Wilfleys.

Tables Nos. 1 and 2 (the No. 5 tables) make four products: a finished concentrate, a first middling which is returned to the head of the table, a second middling which goes to the Wilfley slimers and a tailing. Tables Nos. 3 and 4 make two products—a finished concentrate and a tailing for the slimers. There are five 12-foot Wilfley slimers. The slimes from the five concentrating tables are brought together in a tank and distributed to four of the slimers, each of which makes three products —a finished concentrate, a finishing tailing, and a middling taken from the four last panels. The middling goes to the fifth slimer where two products are made—a concentrate and a tailing. The mill treats 25 tons in 12 hours; the concentration is 15 to 1.

The Boyd Mill.—When visited this mill was in progress of being remodeled. It was said that the process would be: stamps, hydraulic classifiers to four products, Wilfley concentrating tables, and finally Wilfley slimers.

The Henry E. Wood Ore Testing Works.—The ore is crushed in a 9 by 15 Blake crusher to a two-inch size, elevated to a five-stamp battery, passes through a 20-mesh screen and goes by launder direct to a 6 by 15 Wilfley concentrator. This divides into four products—a finished concentrate, a first middling which is returned to the head of the table, a second middling which flows to a reserve tank "T" to be treated later on, and a tailing which is elevated to a 30-mesh trommel. From this trommel the fines go to a settler and the coarse to a second 6 by 15 Wilfley concentrator where two products are made. The first goes to tank "T," and the second product is a tailing. On this last table quartz is in such great excess of the wolframite as to make a clean separation impossible. The settler mentioned is a Dimmick classifier. It will be remembered that this is an ore testing works where the machines are not primarily for the purpose of treating tungsten ores. This classifier is a V-shaped tank of rectangular cross-section, 16 feet by 8 feet, and is 12 feet high. A vertical partition at right angles to the length of the settler divides the tank into two equal compartments. In this partition, near the bottom, is a gate controlled by a rod which extends above the top of the settler. The wolframite with its large quantity of water enters at the top, sinks to the bottom where much of the wolframite and quartz remains; some continues with the water to pass through the gate in the partition to the second compartment through which the water slowly rises and escapes clear at the top, leaving all

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fines and slimes behind. The object of the settler is two-fold: First, to settle the slimes, and, second, to free the slimes from the very large quantity of water which accompanies them into the settler, which excess of water would greatly hinder the work of the slimer. These fines and slimes are tapped from a number of spigots along the bottom of the first compartment and are carried away for treatment on a standard 12-foot Wilfley slimer, which divides into but two products—a finished concentrate and a finished tailing.

The capacity of this arrangement is 7 tons per 10 hours run, but it will be remembered that a part of this has gone to the tank "T" and must receive subsequent treatment. Further, the first Wilfley concentrator was certainly working up to its limit. This was evident by the fact that the streak of concentrates as it crossed the end of the table was 26 inches wide (this is 82% by weight of the total concentrates saved), while the middling streak was 12 inches wide. It seems, then, that in adapting this method to practice, a third concentrator could be used to great advantage. It would receive the contents of tank "T," which at present are sent through the entire process, except, of course, the crusher and stamps, after the regular run has been completed. Its use would form four products—the first, a finished concentrate; second, a first middling to be returned to the head of the table; third, a second middling to be elevated to the trommel, thence to the settling tank as before; and the fourth, a finished tailing. Or, it would be still better to classify at least once and then put the two sizes on two tables instead of overcrowding the one.

The Black Swan Mill.—This mill is near Salina. It is not at present running. The ore is crushed in a 7 by 10 Blake crusher, put through a five-stamp battery, classified into three divisions which go to three Wilfley concentrators. These make three products each—a finished concentrate, a middling which is elevated to the stamp battery, and a tailing which goes to two slimers. The slimers make two products—a finished concentrate and a tailing.

The Red and Bonita Mill.—This mill is a few hundred yards below the Adams claim on Bonita mountain. The mill was erected to treat the ore from the Red and Bonita mine, but the ore was unprofitable and the undertaking was abandoned. The mill is not running at present. The equipment is: Gates crushers, two sets of rolls, jigs, a 10-stamp battery and four Frue vanners.

Ores are seldom hand-picked in Boulder county because the values are often completely covered by the quartz; also, the gangue makes good "mill dirt."

Production and Price.

The figures in the table were taken from Min. Res. (U. S. G. S.) and Min. Ind. (with the exception of the column headed "Average Value").

The American purchasers of tungsten ores are the Primos Chemical Company of Primos, Pennsylvania, and Ash and Deninger of Phoenixville, Pennsylvania. The "unit" scale is adopted in placing the value of a

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tungsten ore, i. e., per unit of 20 pounds WO_3 per ton. Suppose the unit price were $3.00 and an ore contained 60% WO_3, the price would be 60× $3.00=$180.00 per ton. If the ore ran 70% WO_3, the price per unit value would be higher—say $3.50—then a ton would be worth $3.50×70=$245.00.

Table of Production and Price of Tungsten.

Year		Crude Ore Short Tons	Concentrates Short Tons	Value at Mine	Av. Val. Concentrates Sht. ton	% WO_3	Val. per Unit WO_3	Metallic Tungs'n Mfd. Pounds	Value	Average Value
1898	United States...	...	78.865	$17,398	$220	..	$2.0-$6.0	33,200	$43.160	$1.0
1899	United States...	...	201.6	33,600	167	..	1.5- 3.5	45,000	54,000	1.2
1900	San Juan Co. Colo.	...	2.5	.....	...	71	.....	.....	.....	...
		...	3.0	.....	...	68	2.0- 3.5	.....	.....	...
	Boulder Co. Colo.	...	40.0	.....	...	63	.....	.....	.....	...
	Total, U. S.....	...	46.0	11,040	240	..	.....	57,000	51,800	.91
1901	Colorado	...	65.0	8,775	135	60	2.25-3.0	.....	.....	...
	Total, U. S.....	1,221	179.0	27,720	155	..	.....	13,000[1]	7,930	.61
1902	U. S.....	...	184.0	34,040	180	..	1.5	82,000[2]	50,020	...
1903	U. S.....	2,451	292.0	43,639	149	..	3.0	.....	.....	...
1904	U. S.....	...	740.0	184,000	249	60	5.0- 7.0[4]	.....	.....	...
1905	U. S.....	...	803.0	268,676	334	..	.....	.....	.....	...
1906	U. S.....	...	928.0	348,867	376	..	.....	.....	.....	...
1907	U. S.....	...	1640.0	890,048	543	..	.....	.....	.....	...

[1]Also there was manufactured 3,000 pounds sodium-tungstate and 13,000 pounds ferro-tungsten valued at 45 cents per lb.=$5,850.

[2]Min. Res.

[3]Ferro-tungsten: 14,000 pounds at 45 cents=$6,300; sodium-tungstate, 3,500 pounds at 45 cents=$1,575.

[4]Price is for 60% WO_3. P not greater than .25%. S not greater than .01%, N. Y.

PART II.

Physical Properties.

The metal tungsten is of a dark gray color, is opaque and of metallic luster. Its hardness is 6.5, sp. gr.=19.26 (Hadfield), melting point=1,500° C. (Mendelejeff), specific heat=0.036 (Regnault). It is not ductile at common or high temperatures. Atomic weight=184.05*, atomic volume=9.53, atomic density=105. It can be filed and welded. Tungsten alloys with iron, aluminum, and a few other metals.

Uses of Tungsten.

The greatest use for tungsten is an alloy with steel (J. I. & S. Inst., No. 1, for 1893). It makes armor plate very tough and difficult to fracture and split; in projectiles and high speed tools it forms an alloy capable of holding its temper when red hot; it makes car springs stiffer; it increases the permanency of magnets and makes a more powerful vibratory re-

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* "The Atomic Weight of Tungsten," E. F. Smith and F. E. Exner, J. A. C. S., Sept., 1904.

"The Atomic Mass of Tungsten," W. L. Hardin, J. A. C. S., V. 21, p. 1007.

"The Atomic Mass of Tungsten," G. E. Thomas, J. A. C. S., Apl. '99, p. 373.

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sponse in sounding plates and wires for musical instruments. As a filament for electric bulbs it is fast replacing all other materials.

As an aluminum alloy, known to the trade as "wolfram-aluminum," it is made into rolled sheets and plates, which are afterward spun. It is also used for military purposes (American Mfr., Aug. 30, 1900).

It is used for propeller blades when alloyed with aluminum and copper. Because of its lightness and strength, an alloy of aluminum and tungsten is used in French automobile construction.

A variety of "bronze" powder much used in decorating is made by a fusion of potassium tungstate and tin. There are many other alloys made with tungsten.

In the form of sodium tungstate it is a mordant for dying ("Tungsten as a Wool Mordant," Knecht, J. S. C. I., V. 16, p. 667). As calcium tungstate it is used in the Roentgen ray apparatus on account of its fluorescence. Tungsten has the peculiar quality of making fabrics and other vegetable tissues non-inflammable. The material to be treated is coated with H_2WO_4 and glue, or with tungstate of soda and muriatic acid in a thick solution of glue.

Lead tungstate is substituted for white lead as a pigment in paints. Tungsten is used in coloring glass (U. S. G. S., Min. Res., 1901), in the manufacture of stained paper and in glazing porcelain ("Tungsten Glazes for Porcelain," M. A. Granger, Comptes Rendus, V. 2, p. 106).

Mineralogy.*

Wolframite.—$(Fe,Mn)WO_4$ (about 76.5% WO_3). Heavy, dark-gray to black sub-metallic crystals, orthorhombic in appearance, but really monoclinic; also in granular or columnar masses. Hardness = 5 to 5.5; sp. gr. = 7.1 to 7.55; streak, dark-brown to black; opaque, brittle and slightly magnetic. Blow-pipe—Fuses readily to crystalline magnetic globule. In sodium ammonium phosphate (salt phosphorus) yields a reddish-yellow glass which in the reducing flame becomes green. If this bead is pulverized and dissolved with tin in dilute HCl, a blue solution will result. Distinguished from similar iron and manganese minerals by its fusibility and specific gravity.

Hubnerite or Megabasite.—$(Mn,Fe)WO_4$ (75.58% WO_6, 23.4% MnO, 0.24% FeO). Monoclinic. Faces in prismatic zone vertically striated. Often in bladed crystals; also irregular lamellar; coarse divergent columnar; massive granular, the particles strongly coherent. Fracture uneven. Brittle. Hardness = 5 to 5.5. Sp. gr. = 7.2 to 7.5. Luster, sub-metallic, metallic-adamantine, resinous. Color, dark-grayish or brownish-black, brownish-red, hair-brown. Streak nearly black to dark reddish-brown, yellowish-brown, greenish-gray. Opaque or sometimes

*"Wolframite" is taken from Moses and Parsons' "Mineralogy, Crystallography and Blow-pipe Analysis." "Scheelite" is from the same source. "Hubnerite," with the exception of the "Blow-pipe," is from Dana's "A System of Mineralogy."

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translucent. Sometimes weakly magnetic. Blow-pipe—Hubnerite is less fusible than wolframite.

In sodium carbonate bead, reducing flame is red, hot; white, cold.

In sodium carbonate bead, oxidizing flame is red, hot; light-blue, cold.

In salt phosphorus bead, reducing flame is colorless, hot; colorless, cold.

In salt phosphorus bead, oxidizing flame is yellow, hot; colorless, cold.

In borax bead, reducing flame is yellow, hot; reddish-brown, cold.

In borax bead, oxidizing flame is yellow, hot; dark-red, cold.

Scheelite.—$CaWO_4$ (CaO=19.4%, WO_3=80.6%), sometimes with replacements of Mo. Heavy brownish-white, pale-yellow, gray or green masses and square pyramids. Also drusy crusts of yellow or brown crystals. Tetragonal. Hardness = 4.5 to 5. Sp. gr. = 5.4 to 6.1. Streak, white. Adamantine luster. Distinct cleavage parallel to first order pyramid, also indistinct cleavage parallel to the second order pyramid. Blow-pipe—Fusible with difficulty on sharp edges. In salt, phosphorus forms a clear bead, which in the reducing flame becomes deep-blue and if the bead is powdered and dissolved in dilute HCl, it yields a deep-blue solution, especially on addition of metallic tin.

Metallic Tungsten B. B.

In borax bead, oxidizing flame is colorless, hot; colorless, cold.

In borax bead, reducing flame is colorless, hot; yellowish-brown, cold.

In salt phosphorus bead, oxidizing flame is colorless, hot; colorless, cold.

In salt phosphorus, reducing flame is greenish, hot; blue, cold.

With tin or charcoal it becomes dark green. Interfering element—iron, the salt phosphorus bead in the reducing flame is then yellow, hot, and blood-red, cold.

The other minerals containing tungsten, but of no present economic value, are:

Stolzite—$PbWO_4$

Raspite—$PbWO_4$

Wulfenite—$(Pb,Mo)WO_4$

Cuprostungstite—$CuWO_4$

Cuproscheelite—$(Ca,Cu)WO_4$

Powellite—$(Ca,Mo)WO_4$

Tungstite—WO_3, (yellow earthly mineral occurring with wolframite).

Meymacite—(An alteration from scheelite).

Pyrachlore.

Yttro-Tantalite.

Columbite.

Hielmite.

Samarskite.

Chemistry.

The Metal.—Tungsten "W" does not oxidize in either dry or wet air. It is attacked but slowly by the common acids. The pure metal is obtained by heating the canary yellow trioxide to bright redness in a platinum or

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porcelain tube in a current of hydrogen (Roscoe). It can be reduced also by carbon, or, more conveniently, by finely divided aluminum.

Oxides.—Tungsten forms a dioxide (WO_2) which at elevated temperatures, or at a low red heat in presence of oxygen gas or steam, takes up oxygen and forms the trioxide (WO_3) which is canary yellow. This is the anhydride of tungstic acid. WO_3 can be reduced by zinc. When a tungstate is treated with an acid at an elevated temperature the anhydride (WO_3) is formed, but at lower temperatures tungstic acid (H_2WO_4) is precipitated. If tungstic acid is ignited in a stream of hydrogen, a blue tungstate of the oxide of tungsten is formed; with a stronger heat, brown oxide, and at a still higher heat, metallic tungsten is formed as a gray crystalline powder.

Reducing Power of Tungsten.—Tungsten does not reduce silica, alumina, magnesia, nor oxide of zinc. It easily reduces oxides of tin, lead and copper at the temperature of the ordinary Bunsen flame.

Chlorides.—Tungsten forms a number of chlorides which, in general, correspond to the chlorides of molybdenum. The tri-chloride of tungsten, however, is not known, while a hexachloride exists, but this has no counterpart among the chlorides of molybdenum. The dichloride (WCl_2) is obtained as the lowest reduction of the hexachlorides in a current of hydrogen. The tetrachloride (WCl_4) is formed by heating the pentachloride in an indifferent gas. The pentachloride (WCl_5) is formed by distilling the hexachloride which gradually loses chlorine when volatilized. The hexachloride (WCl_6) is formed by heating the metal in a current of chlorine. Tungsten also forms the oxychlorides $WOCl_4$ and WO_2Cl_2.

Salts.—Tungsten occurs in nature mainly in the form of salts of tungstic acid. When the oxide is dissolved in strong alkalies the corresponding salt is formed (X_2WO_4).

HCl added to a salt gives a white precipitate (H_2WO_4) which on boiling turns yellow.

Metallic tin and an excess of HCl imparts to WO_3 a blue color changing to brown, due to the formation of lower oxides of tungsten.

Ammonium sulphide added to the solution of ammonium tungstate produces no precipitate, but forms the soluble sulpho-salt $(NH_4)_2WS_4$. On adding HCl to this solution, brown WS_3, tungstic sulphide, is precipitated. The supernatant liquid is generally blue.

Quantitative Determination of Tungsten (Oliver P. Fritchle).—In hydrofluoric acid is found the ideal solvent for both tungstic and silicic oxides, and upon these facts the following method is founded: Weigh into a platinum dish or crucible of about 25 cc. capacity one-half gram of the finely powdered ore, add equal quantities of HCl and HF, and digest at slow boiling temperature for about one hour or until the ore is all in solution, adding from time to time more of each acid. Evaporate down to about one-half the original volume to displace the silicon fluoride and excess of HF. The dish should be covered to prevent loss by spattering.

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The two acids will entirely dissolve most ores excepting those containing tin oxides, in which case it will be necessary to filter off the insoluble residue.

Transfer the solution to a No. 3 beaker, add 20 cc. HCl and 8 cc. HNO_3, cover and boil down to about 10 cc., to expel all hydrofluoric acid. The tungstic fluoride will be converted into the chloride and, in the presence of HNO_3, will be precipitated as tungstic acid (H_2WO_4). Dilute with 50 cc. of hot distilled water and boil slowly for about half an hour, or until the tungsten is all precipitated, when the beaker should be set back and kept just below boiling point until the solution is clear. Filter through a Gooch crucible onto an asbestos felt, wash well with hot water, dry, ignite for five minutes, cool and weigh as WO_3—a bright canary colored oxide.

A Volumetric Method for the Determination of WO_3 (Zellner).—This method can be used where great accuracy is not required. Fuse the weighed and powdered mineral in a platinum crucible with three parts sodium carbonate and one part nitre, cool and dissolve the mass in hot H_2O. Filter. Make the filtrate very slightly acid with acetic acid, dilute to 200 cc., boil and titrate while boiling.

The standard solution for titrating consists of 16.3 grams of pure crystallized lead acetate dissolved in a litre of H_2O, which should be slightly acidified with acetic acid. When titrating, a white precipitate comes down and rapidly settles when vigorously stirred with a glass rod. The end point is marked by the lead acetate solution giving no precipitate or causing no cloudiness.

Qualitative Determination of Wolframite.—In order to effect a qualitative separation, for obtaining tungstic acid, the very finely powdered mineral is digested with a mixture of concentrated hydrochloric acid and about one-fourth of nitric acid, until it is converted into yellow, pulverulent tungstic acid. This is filtered off, washed, dissolved in ammonia, the solution filtered, and evaporated to crystallization. By this treatment, there is left behind undissolved, besides the undecomposed particles of mineral which have not been finely powdered, a white substance, consisting of silica and niobic acid, of which latter the wolfram contains about 2%. In order to remove the silica, it is repeatedly evaporated with hydrofluoric and sulphuric acid, then fused with bisulphate of potassium and further treated with hot water and filtered. On igniting the salt in the air, pure tungstic acid is left.

Or, three parts of the mineral, very finely powdered, may be mixed with an equal quantity of carbonate of potassium, or two-thirds dry carbonate of soda, the mixture heated to redness for half an hour, and the tungstate of potassium, which is formed, may be extracted from the cooled mass with water. If the solution is green from the presence of a manganate, it may be decomposed by adding a little ammonia and warming. On dissolving the residual sesquioxides of Fe and Mn in concentrated hydrochloric acid, columbic acid remains behind.

Pure tungstic acid may be obtained from this solution by boiling and adding, drop by drop, hydrochloric or nitric—not too dilute—until there is

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a small excess. From the solution neutralized with hydrochloric acid tungstate of lime may be precipitated by chloride of calcium. The tungstate may be decomposed, after washing, by boiling hydrochloric acid.

Quantitative Determination of Wolframite (Wohler's "Mineral Analysis").—The lixiviated mineral is digested with a mixture of four parts of concentrated HCl and one part of HNO_3, until it is completely decomposed. The solution is then evaporated to dryness, which operation should be finished on the water-bath, the chloride of manganese and sesquichloride of iron dissolved out, the tungstic acid filtered off, washed with alcohol, dissolved in ammonia, and separated by filtration from the columbic acid. The clear solution is evaporated, the residual ammonia-salt ignited with access of air, and the tungstic acid weighed.

When tin is present it can be separated from the tungsten in one of two ways: (a) Ignite the oxides of tungsten and tin repeatedly with ammonium chloride to constant weight. The tin is volatilized as stannous chloride while the tungstic acid remains. (b) Fuse the mixture of the two oxides with potassium cyanide and extract the fusion in HCl; the tin is reduced to the metallic state, and afterwards dissolved in HCl; while the tungstic acid remains, is ignited and weighed.

Or the lixiviated mineral is ignited in a platinum crucible, with three parts of carbonate of potassium, the mass dissolved in water, and the residual oxides thoroughly washed. The solution is neutralized with HNO_3, and the tungstic acid precipitated by nitrate of suboxide of mercury, the free HNO_3 being afterward neutralized with a few drops of ammonia, so that a black precipitate begins to appear. The precipitate is thoroughly washed, a very dilute solution of nitrate of suboxide of mercury being used at last, since otherwise the precipitate is liable to pass through the filter. The precipitate is then dried and ignited, when pure tungstic acid is left.

Determination of Scheelite (Wohler, "Mineral Analysis").—The mineral, very finely powdered, is digested with concentrated HNO_3, the mass evaporated nearly to dryness, mixed with alcohol and filtered. The residual yellow tungstic acid is washed with alcohol, ignited and weighed. The alcohol is expelled from the solution by evaporation, the latter neutralized with ammonia, and the lime precipitated by oxalate of ammonia.

Determination of Hubnerite (Wohler "Mineral Analysis").—Fuse one gram of the finely pulverized ore with mixed carbonates of soda and potash; extract the melt with boiling water and filter. The tungstic acid and silicic acid are in the solution as the corresponding salts of the soda and potash, while the manganese and iron are on the filter as oxides. Dissolve the Mn and Fe in HCl, add 75 ccs. of H_2O and an excess of zinc oxide, boil, filter and titrate the solution for manganese with standard solution of potassium permanganate. Dissolve the zinc oxide and precipitate in dilute H_2SO_4 plus 3 ccs. of HCl, add zinc, reduce and titrate for iron with potassium permanganate. Tin is separated as under wolframite.

To the first filtrate add excess of HCl and evaporate to dryness. Ignite the residue and weigh it. This gives silica plus tungsten trioxide.

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Treat this residue with HF and finally with ammonium fluoride, ignite and weigh. The remaining weight is tungsten trioxide, while the loss is the silica.

General.—A colloidal solution of tungstic acid is obtained by treating sodium tungstate with HCl and dialyzing the mixture. The tungstic acid remains behind in the form of a colloidal solution which on evaporation forms a gummy mass. Tungsten also forms polytungstic acids, by the polymerization of tungstic acid and the loss of one or more molecules of water. Salts of the acid $H_2W_4O_{13}$ are known. This is obtained from four molecules of tungstic by loss of three molecules of H_2O:

$$4H_2WO_4 = 3H_2O + H_2W_4O_{13}.$$

Tungsten trioxide combines with other acids like molybdenum oxide, forming complex acids. The best known of these are the compounds with arsenic, phosphorus, and iodic acid. These are known as arsenitungstates, phosphotungstates, iodotungstates, and the like.

With a view of finding a quick volumetric method for tungsten by pertungstates, the following experiments were made. Nothing came from them, but they are of interest "per se." A solution of one gram of sodium tungstate in 50 ccs. H_2O (made slightly acid with H_2SO_4) was made up; this I shall call the "standard tungsten solution." A fresh solution of ferrous sulphate was made up and diluted to such an extent as to require 8 ccs. of a normal solution of potassium permanganate to oxidize 50 ccs. of the ferrous sulphate to ferric sulphate; this I shall call the "standard ferrous sulphate solution."

To 10 ccs. of the salt of a metal (for instance, silver nitrate), 50 ccs. of standard tungsten solution were added and the result noted. To this was added 5 ccs. H_2O_2 and again the result noted. This solution was filtered, the precipitate washed and placed in 50 ccs. of the standard ferrous solution and titrated. Results:

Nitrate of	Sodium tungstate	Sodium pertungstate	Permanganate required
Ag.	heavy white ppt.	heavy white ppt.	7 ccs.
(ous) Hg	yellow-white ppt.	heavy yellow-white ppt.	8+ccs.
(ic) Hg	no ppt.	no ppt.	
Pb	heavy white ppt.	heavy white ppt.	6.8 ccs.
Co	no ppt.	no ppt.	
Al	light white ppt.	very slight ppt.	
Ca	no ppt.	no ppt.	
Mg	no ppt.	no ppt.	
Bi	light white ppt.	heavy white ppt.	6.3 ccs.
Fe	no ppt.	slow brown-red ppt.	
Cu	no ppt.	no ppt.	

When H_2O_2 and NH_4OH are combined, oxygen is given off. When H_2O_2, NH_4OH and sodium tungstate are combined the oxygen is given off much more rapidly. To show the value of this method of generating oxygen for the lecture table, the following experiments were made. An apparatus was set up for catching the oxygen given off from a 300 cc.

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flask into which 50 ccs. H_2O_2 were placed, followed by 50 ccs. NH_4OH. A similar apparatus was set up beside the first one, in order to have temperature conditions as nearly similar as possible, and into the flask was placed 50 ccs. H_2O_2, 50 ccs. NH_4OH and 2 ccs. standard tungsten solution. For the first minute or two the oxygen given off by the first apparatus was equal to that given off by the second, which contained the tungsten, but quickly ceased all action, while the second, after a pause of several minutes, became again active, giving off a continuous and very regular flow of oxygen, the amount depending upon the temperature of the room. After from 40 to 50 minutes the action in the second ceased. Both were allowed to stand for half on hour and then the contents of the first were placed in the flask of the second, and again action began and continued regularly for from 30 to 40 minutes. The results:

				Oxygen given off from		
Experiment	H_2O_2	NH_4OH	Standard	No. 1	No. 2	Combined
1.....	50 ccs.	50 ccs.	2 ccs.	185 ccs.	10 ccs.	175 ccs.
2.....	50 ccs.	50 ccs.	2 ccs.	220 ccs.	40 ccs.	145 ccs.
3.....	50 ccs.	50 ccs.	2 ccs.	340 ccs.	30 ccs.	210 ccs.
4.....	50 ccs.	50 ccs.	2 ccs.	285 ccs.	15 ccs.	230 ccs.
5.....	50 ccs.	50 ccs.	2 ccs.	280 ccs.	30 ccs.	165 ccs.
6.....	50 ccs.	50 ccs.	2 ccs.	480 ccs.	55 ccs.	390 ccs.
7.....	50 ccs.	50 ccs.	1 cc.	405 ccs.	95 ccs.	255 ccs.
8.....	50 ccs.	50 ccs.	1 cc.	510 ccs.	15 ccs.	395 ccs.

There are many compounds and combinations between tungsten and various elements which have been investigated and which are referred to. See "Handbuch der Anorganischen Chemie," Dr. O. Dammer, V. 3, p. 632. For detail of the complex inorganic acids of tungsten, see "Derivatives of Complex Inorganic Acids," Allen Rogers and Edgar F. Smith, J. A. C. S., Nov., 1904; also, "Derivatives of New Complex Inorganic Acids," Allen Rogers, J. A. C. S., March, 1903, p. 298; and, "Derivatives of Complex Inorganic Acids," Allen Rogers and Edgar F. Smith, J. A. C. S., Dec., 1903, p. 1223.

Metallurgy.

Tungsten, to be used in the manufacture of steel, should contain not more than a small per cent. of sulphur and phosphorus. Phosphorus seldom occurs with tungsten ores in large enough quantities to require a separation. This separation could not be done to advantage here, because the process requires a somewhat elaborate apparatus. It is the work of the refinery. The separation of sulphur, which in the San Juan region occurs with tungsten to a considerable extent, can readily be accomplished at the mill with an electro-static separator. See "Separation of Sulphur from Hubnerite".

To obtain impure metallic tungsten from a concentrate freed from these impurities, the finely ground mass (FeO, MnO, CaO and WO_3) is heated with charcoal to 1,500°C. in a charcoal-lined crucible. The tungstic acid is reduced to metallic tungsten. The electric furnace is much used in the reduction of WO_3; the product is 99% pure. See "Electric Preparation of Tungsten," Comptes Rendus, V. 123 1896; "Manufacturing of Ferro-

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Alloys in the Electric Furnace," Electro-Chemical Industry, Sept., Oct. and Nov., 1904.

Compounds of tungsten are manufactured mostly by Oxland's method, which is to fuse the ore in a reverberatory furnace with soda ash and sodium nitrate. The soluble sodium tungstate dissolves out and is obtained by crystallization. The production of ferro-tungstates is gone into in detail by R. A. Hadfield, "Alloys of Iron and Tungsten," J. I. & S. Inst., 1903, Part 2, p. 36. In this article is given an excellent description of the manufacture of tungsten from wolframite as practiced by the Tungsten and Rare Metals Company (Ltd.), Queen's Road Station, Battersea, London. The Holloway-Lake process of making tungstates is to add tungsten in a finely divided state to a fused bath of silicate of an alkaline metal capable of combining freely with the Fe or Mn or Ca in the ore, whereby practically pure tungstate of the alkaline metal is produced at one operation. This process is protected by United States patent No. 667705, G. F. Holloway and H. W. Lake, London.

Though scheelite contains 68 to 75% WO_3, against 65 to 70% WO_3 in wolframite, the latter is preferable in the manufacture of pure tungsten.

When wolframite is smelted with tin it impedes the reduction of the tin and facilitates its scorification. At Cornwall, England, South Dakota and at a number of other places, the association of tin ores with wolframite is common.

Alloys.

The alloys for which tungsten is most used are with iron and steel. Ferro-tungsten (37% tungsten) is the usual form in which the tungsten is added to iron or steel to form the desired alloy. Tungsten powder is also used for this purpose. There are iron-tungsten alloys of from 1% up to 80% tungsten, but the combinations and resulting products are too many to enumerate here. For a complete treatise of this subject see: "Alloys of Iron and Steel with Tungsten," J. I. & S. Inst., 1903, Part 2, p. 28; "Production of Ferro-Tungsten," p. 36 of the same; also see J. I. & S. Inst., No. 1 (1895); "Alloy Steels," Eng. Mag., Dec., 1904, p. 443, by Leon Guillet. This is an abstract from his paper contributed to the Memoires of the Societe des Ingenieurs Civils de France; "Properties and Uses of Ferros," Min. Wld., Dec. 3, 1904; "The Production of Alloys of Tungsten and of Molybdenum in the Electric Furnace," C. L. Sargent, J. A. C. S., V. 22, p. 783.

Aluminium (metallic) can be hardened with tungsten. Its resistance to oxidization makes it much superior to copper. See "Tungsten, Its Use and Value," M. & S. P., Dec. 17, 1904.

Partinium ("Tungsten," J. H. Pratt, Min. Wld., Dec. 3, 1904,) is an alloy of aluminium and tungsten. It is used by the French in automobile construction because of its lightness and strength.

Sideraphite ("Tungsten," J. H. Pratt, Min. Wld., Dec. 3, 1904,) is an alloy containing a large proportion of iron, some nickel, aluminium and copper, and 4% of tungsten. It resembles silver in appearance, is very ductile, malleable and not easily attacked by acids.

Minargent ("Tungsten," J. H. Pratt, Min. Wld., Dec. 3, 1904,) is an alloy of copper, nickel, and tungsten.

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Backford, or Brittannia metal, is an alloy of copper, tin and tungsten. (Hadfield).

The Blackwell Company manufactures a tungsten-nickel alloy which consists of 73 to 75% of tungsten, 23 to 25% of nickel, and 2 to 2½% of iron, .75 to 1% of carbon, and .25 to .50% of silicon (Pratt).

Platinoid consists of 60% copper, 25% zinc, 14% nickel and 1 to 2% of tungsten. It has a high electrical resistance, which does not decrease with heat (Hadfield).

An alloy of tungsten, aluminium and copper is used in the manufacture of propeller blades. See "Tungsten," Min. Res. U. S. G. S., 1901.

A series of unnamed alloys have been made by L. P. Hamilton and Edgar F. Smith, J. A. C. S., March, 1901, p. 151, which consist of tungsten and copper and aluminium, tungsten-iron-titanium-carbon, and tungsten-iron-columbium-tantalum.

The following sets forth the work of the writer in experiments with various metals in an endeavor to form alloys with tungsten. No alloy resulted from the following mixtures under conditions used: Copper and tungsten, the latter is .25 per cent., .50 per cent., 1 per cent. and 2 per cent.; silver and .75 per cent., .50 per cent., 1 per cent., 10 per cent. tungsten; lead and .25 per cent.; .50 per cent., 1 per cent. and 2 per cent. tungsten; tin and .50 per cent., 1 per cent. 1.5 per cent., 2 per cent. and 4 per cent. tungsten; aluminium and .5 per cent. tungsten; silver 95 per cent., tin, 5 per cent., and tungsten, 1 per cent.; silver, 90 per cent., copper, 8 per cent., tungsten, 2 per cent.

An alloy was formed with aluminium and 1 per cent. and 10 per cent. tungsten and nickel, 5 per cent. and 10 per cent. tungsten.

The metal of the larger per cent. was placed in an assayer's crucible and heated in the combustion chamber of a gasolene furnace, which has a reducing atmosphere at a temperature of from 1100° C. to 1500° C. When the metal had been thoroughly melted the metallic tungsten wrapped in paper was dropped into the crucible, which had been taken from the furnace, and the crucible immediately covered with a scorifying dish and again placed in the furnace. At intervals the metals were stirred without taking the crucible from the furnace. Fifteen to thirty minutes after the tungsten was added the crucible was withdrawn, but kept covered, and allowed to cool.

The method of preparing the possible alloys for chemical analysis was to break the crucible, clean the bee-hive shaped metal with a file and obtain a sample by drilling about one-half of an inch into the metal.

All analyses were qualitative. The copper alloys were each boiled with HNO_3. The solution was clear, with no evidence of WO_3. The solution was taken down to dryness and the residue taken up with HNO_3 and H_2O. The solution was clear, therefore no WO_3 present.

The silver alloys were each dissolved in HNO_3, sodium chloride was added, the silver chloride filtered out, the filtrate taken down to dryness and the residue taken up with water; everything went into solution, therefore there was no WO_3.

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The lead alloys were each dissolved in HNO_3, taken down to dryness and the residue taken up with HNO_3 and H_2O; as everything went into solution, there was no WO_3.

The tin alloys were each dissolved in aqua regia taken down to dryness, the white powder thus formed was taken up with concentrated HCl, but not all of the powder went into solution; water was added, boiled and filtered and the filter paper burned; there was on evidence of WO_3. The ash of the filter paper and the white powder was fused with equal proportions of sodium carbonate and sulphur, the melt dissolved in water, filtered, and to filtrate HCl was added and a yellow precipitate obtained. Had tungsten been present a brown precipitate would have formed, therefore there was no. WO_3. A color check was run by putting metallic tungsten through a parallel process.

The aluminum alloys were each dissolved in aqua regia, taken down to dryness and taken up with water and HCl. A bright yellow precipitate remained, which was filtered, burned and fused with sodium carbonate. The melt was dissolved in water, filtered, and to the filtrate, sodium tungstate, HCl was added. A white precipitate formed, which, on boiling, became canary yellow; therefore tungsten was present. The object in running the aluminium and nickel, which were known to alloy readily with tungsten, was to see if they would alloy under the conditions imposed upon them in following this method and which method was paralleled in the case of the other metals experimented with.

The nickel alloys were each dissolved in dilute HNO_3, taken down to dryness and taken up with HNO_3 and water, leaving a yellow precipitate, which was treated as given above for aluminium; the same result was obtained; therefore tungsten was present.

The silver, tin, tungsten alloy was dissolved in HNO_3, boiled, filtered and washed until washing gave no indications of silver. The precipitate was dissolved in ammonium hydrate (any tungsten would form ammonium tungstate), and to the filtrate aqua regia was added and boiled to dryness. The residue was fused with sodium carbonate, dissolved in water, heated, and filtered. The residue was strongly acidified with HCl, taken down to dryness, dissolved in water. As everything went into solution there was no tungsten present.

The silver, copper, tungsten alloy was dissolved in HNO_3. Everything went into solution. The solution was boiled to dryness, taken up with HNO_3 and water—again a clear solution, therefore no tungsten.

Separation of Sulphides from Hubnerite.

As stated in the chapter on the San Juan district, pyrite occurs with the hubnerite; also occasionally chalcopyrite, galena, and blende. Since the greatest present use of tungsten is as an alloy of steel, it becomes necessary to free the hubnerite from sulphur, which causes red shortness in steel when present to the extent of .05% or more. One-hundredth of one per cent. is not detrimental.

In order to accomplish this separation, experiments were made as follows: The concentrate from the Red and Bonita mill, which procured its hubnerite from the Adams vein, was placed in a Blake-Morscher electro-

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static separator and divided into two products, A and B, the former containing the hubnerite nearly freed from pyrite. The principle of this machine is that minerals having different degrees of electro-conductivity can be separated by inducing an electro-static charge into the mixture and then changing the polarity of that charge to the polarity of the charging device as the mixture comes in contact with the charging device. This causes repulsion of the charged mineral from the mixture. This is accomplished by passing the mixture first near to the charging device, which is a steel bar charged with from 5,000 to 40,000 volts of static electricity. This induces a charge in the mixture of the opposite polarity to that of the bar. When the mixture is brought in contact with the bar the charged mineral will change its polarity to that of the bar and will be immediately thrown outward leaving the uncharged mineral to fall into a separate receptacle.

The Red and Bonita concentrate runs from 30 to 200-mesh. These separators do much better work on a sized than upon an unsized product. So a few pounds of the concentrate were bucked down until it all passed through an 80-mesh screen, but no low limit was set or any mineral discarded. This was then put through the separator and was divided into lots A′ and B′. An analysis was made of the four products. Small samples of A and A′ were then roasted over a very strong Bunsen flame for one hour and again analyzed. Part of each of the roasted products was then boiled in water for ten minutes, the idea being that some of the sulphur might have formed soluble sulphates, decanted, washed and again analyzed, with the following results;

	WO_3	Sulphur
(1)—Concentrate as it came from the mill	71.80%	6.115%
(2)—(1) after being separated in the machine	64.21	.598
(3)—(2) after being roasted	...	.175
(4)—(3) after being boiled	...	.120
(5)—Concentrate from mill sized to 80-mesh (max.)	71.80	6.115
(6)—(5) after being separated in the machine	67.47	.344
(7)—(6) after being roasted	...	.082
(8)—(7) after being boiled	...	.077

Steel is alloyed with tungsten in amounts of from 1 to 10% tungsten; above 3% brittleness is produced. For magnet-steel 5 or 6% is used; for tool-steel as high as 10%, but this is cast. Ferro-tungsten is 37% tungsten, but the steel-tungsten alloy that has to stand the test for brittleness will not contain more than 3% tungsten. Three per cent. of tungsten containing .12% of sulphur will bring but .0036% of sulphur into the alloy, which is a very safe percentage.

Abbreviations.

E. and M. J.—Engineering and Mining Journal.

J. A. C. S.—Journal of the American Chemical Society.

U. S. G. S.—United States Geological Survey.

J. S. C. I.—Journal of the Society of Chemical Industry.

J. I. & S. Inst.—Journal of the Iron and Steel Institute.

Trans. Am. I. of M. E.—Transaction of the American Institute of Mining Engineers.

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Aust. M. Stan.—Australian Mining Standard.
Min. Res.—Mineral Resources. (U. S. G. S.)
Min. Ind.—Mineral Industry.
Min. Wld.—Mining World.
Min. Rep.—Mining Reporter.
Min. Jl.—Mining Journal.
Eng. Mag.—Engineering Magazine.
Proc.—Proceedings.

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Addendum.

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Since the time the preceding article was issued from the departments of Chemistry and Geology of the Colorado School of Mines, much activity has taken place in both the mining and the metallurgy of tungsten. There has been a steady rise in production and value prior to 1908, when, although in an advanced state of industry, a slump similar to that of 1901 took place. In May, 1907, the value per unit of tungsten reached the high notch at $11.00, with a few scattering purchases above this quotation. The spring of 1908, however, saw a drop to $5.00 per unit, but the market has been slowly recovering since then. It is certain that the output and value for 1908 will not approach that of 1907. As a result of this inactivity, tungsten mines and mills were at a standstill for about one year.

Needless to say, the interim, 1905-07, when the tungsten market grew to its fullest, was one of activity. The single instance of the Colorado Tungsten Corporation mines will suffice. In 1905, the development consisted of a shaft 145 feet deep, with no drifts. Since then two shafts several hundred feet have been sunk and from these many hundred feet of drifts have been opened in levels which have opened up ground to the surface. Almost 600 tons of concentrates have been removed, which represent 5,558 tons of ore.

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Similar advance in development has been reached in the Wolfe-Tongue and Great Western Exploration Co.'s mines.

There has been little or no activity in the northeastern belt in the neighborhood of Ward. This is due in part to the nature of the ore, which is pyritic.

On the other hand, the belt has been extended farther south across the Boulder County line, a short distance into Gilpin County, near Rollinsville, on the Denver, Northwestern & Pacific Railroad.

The most active of the companies operating here is the Tungsten Mines Company, whose property lies on Beaver Creek, two and one-half miles north of Rollinsville.

Here the general character of the ores remains the same as at Nederland. The granite schist and dyke rock walls are similar to the formations to the north, and the ore is crystalline and capable of high concentration. In fact many specimens were taken from this region, which showed crystallized ferberite to the naked eye. One specimen consisted of a twenty-pound mass of crystals the size of large peas.

The property of the Tungsten Mines Company consists of seventeen claims, which cover a total acreage of fifty-five acres. Some of the land is well timbered. Claims are reached by good wagon roads, either down Beaver Creek to South Boulder Creek, or to Rollinsville, at both points connecting with a railroad.

The group covers a main vein and various spurs, dips and angles. The general course of this vein system is N. 65°E., and various tunnels, shafts and open cuts disclose it from the Elsie shaft and tunnel on the south, to the Mammoth on the north, which extremes are about fifteen hundred and eighty feet apart.

The quantity of crude ore removed in 1906-07 equals 346 tons, which yielded about 26 tons of concentrates.

The ore bodies on the Elsie and Mammoth claims are strong and persistent. The pay streaks vary from several inches to two and one-half feet, with considerable mill dirt between these and the hanging walls.

A noteworthy attempt by German interests to mine and mill the refractory ore on the "Rogers Patent" was begun in 1907, but work ceased with the fall in price in the latter part of the year. The property consists of 2,000 acres of mineralized land acquired under agricultural patent prior to tungsten mining in the district.

The total output for Colorado during the last few years is as follows:

	Tons Concentrates.	Value.
1904	148	$ 33,200
1905	720	216,000
1906	823	352,150
1907	1,170	569,905

A comparison between the production of tungsten ore in the United States and especially Colorado, with the Queensland and Cornwall productions, proves interesting.

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	Queensland Concentrates.	Value.	Cornwall Concentrates.	Value.
1906.....	710 l. t.	$284,565	251 l. t.	$ 73,524
1907.....	87 l. t.	51,100	312 l. t.	170,000

No great advance over the present milling practice has as yet been demonstrated. Present practice, especially with ores of non-crystalline character, involves the use of stamps, and consequently much sliming. Efforts directed to the recovery of values in the slime have helped somewhat, but it is believed that recovery of over sixty per cent. of the tungsten values is rare. At times the recovery falls far below this. In other instances where the ore, even when highly brecciated, is of crystalline character, as high as eighty per cent. of the values is recovered.

Much interest was felt in the operation of the large mill, which was put in operation in 1907 on the "Rogers Patent." Here an entirely new departure in tungsten milling in America was tried, but at the time of cessation of work no important results were disclosed. The method of concentration did away with stamps altogether and employed crushers, rolls, classifiers, jigs, and tables.

Following this principle to avoid sliming, but along modified lines, the Lehigh Valley Mining and Milling Company is reported to have accomplished remarkable results.

MINERALOGY.

Ferberite is described by Dana as follows:

Cryst. Monoclinic.

Massive, granular.

Cleavage perfect.

Hardness 4-4.5.

Luster imperfectly vitreous, a little submetallic adamantine.

Color, black, opaque.

Streak, brownish black to blackish brown.

Composition, ferrous tungstate.

In wolframite the ratio of iron to manganese is chiefly 4:1 and 2:3, but may vary from 9:1 to 2:3.

A characteristic analysis of Nederland tungsten concentrates shows the following:

WO_3	63.20%
FeO	20.36%
MnO	1.10%
SiO_2	15.00%
P	Tr.
S	.50%
Au	Tr.
Ag	2.4 oz.

Composition and other characteristics of so-called Boulder County wolframite correspond well with the mineral ferberite.

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